

# Comparison of the experimental and theoretical pressure fields in the nearfield of ultrasonic transducer-lens systems

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(Received 22 April 1980; accepted for publication 23 June 1980)

Experimental measurements of acoustic pressure fields near the focal points of ultrasonic transducer-lens systems are compared to calculations of a recently developed analytic technique. This method incorporates the Fresnel approximation to expand the field in terms of Gaussian-Laguerre functions to calculate the acoustic field for arbitrary placement of a lens in the nearfield of a circular transducer. The predicted field pattern symmetries near the focal region with a lens located either at one focal distance or at the transducer face are confirmed by experimental measurements made with a microsphere probe.

PACS numbers: 43.20.Rz

Recently reported results of Cavanagh and Cook<sup>1,2</sup> establish a method for calculating the acoustic pressure fields in circular ultrasonic transducer-lens systems. Unlike other techniques, this method permits the determination of pressure fields when a lens is placed at an arbitrary position on axis in the nearfield of a circular piston transducer. These calculations indicate that significant spatial field changes occur in the focal region when the position of the lens shifts. In particular, they predict spatial symmetry of the field about the focal plane when the lens is placed on focal length from the transducer; similarly, with the lens located at the surface of the transducer, they predict a pressure maximum shifted towards the transducer rather than at the geometric focal point. This last fea-

ture is a known fact of physical optics and has been confirmed experimentally many times.

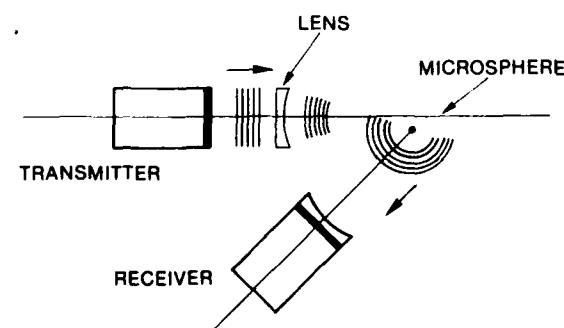


FIG. 1. Experimental apparatus for measurement of pressure fields. The microsphere and receiver remain at a fixed position while the source field is processed through their viewing window.

<sup>a</sup>Work performed while at the U.S. Naval Research Laboratory, Washington, D.C., under auspices of Physical Acoustics Center, Code 5130.

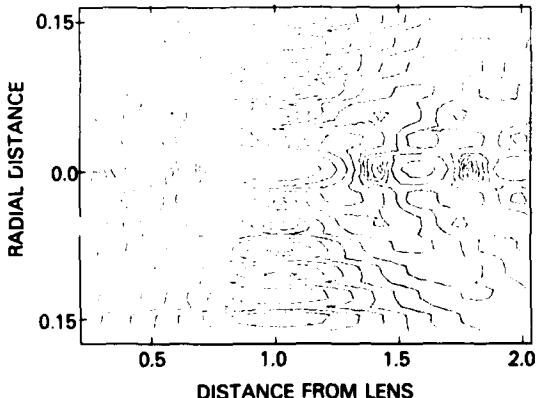
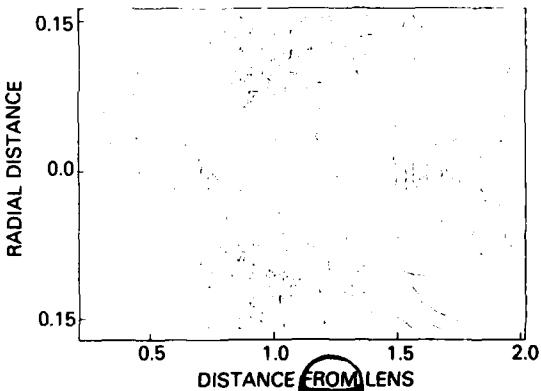


FIG. 2. Calculated pressure field for lens mounted at transducer face (upper) and at one focal distance from the transducer face (lower). Dimensions are in inches.

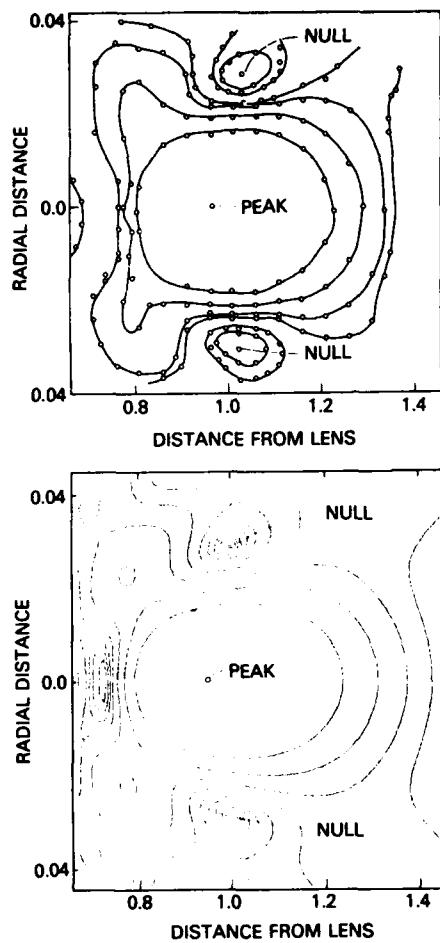


FIG. 3. Experimentally measured (upper) and calculated (lower) pressure contours for lens mounted at transducer face.

Experimentally measured values are here compared with calculated values of the field in the region near the focal point for a circular transducer of 0.5 in. diam operating at a frequency of 5.0 MHz. A lucite lens with a focal length of 1 in. was placed coaxially both at the transducer face and at one focal distance from the transducer face. The resulting pressure field was measured by moving a microsphere in rasterlike fashion through the focal region; the technique, developed by Edwards and Jarzynski,<sup>3,4</sup> utilizes the amplitude of the scattered wave as a measure of the field strength at the microsphere location (Fig. 1). In this arrangement, the microsphere is positioned at the focal point of the receiver and both are held at a fixed position during the course of the experiment. The transmitter and lens system is positioned so that the microsphere interrogates the desired region of the pressure field. The microsphere has a radius of approximately 0.001 in., sufficiently small so that even the focused field presents essentially a uniform field over the area of the sphere. At 5.0 MHz, the product of waveconstant and diameter,  $ka$ , is approximately 0.5. The amplitude of the scattered wave is therefore relatively independent of the scattering

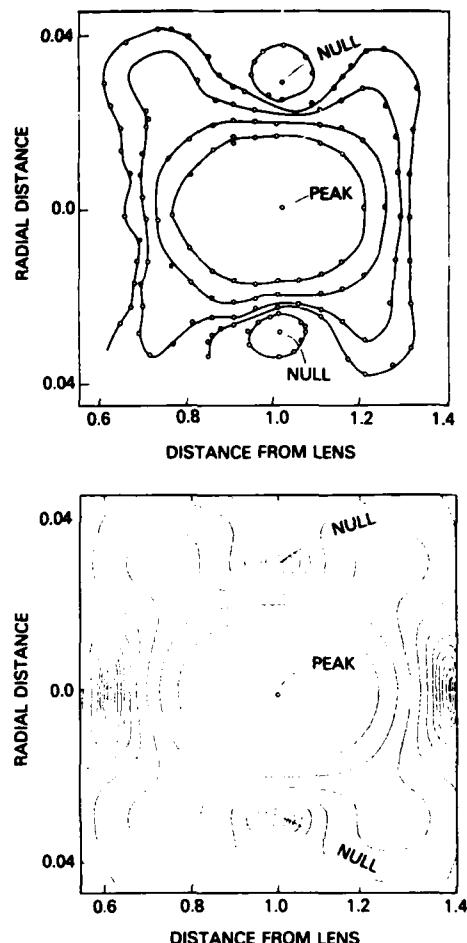


FIG. 4. Experimentally measured (upper) and computed (lower) pressure contours for lens mounted at one focal distance from transducer face.

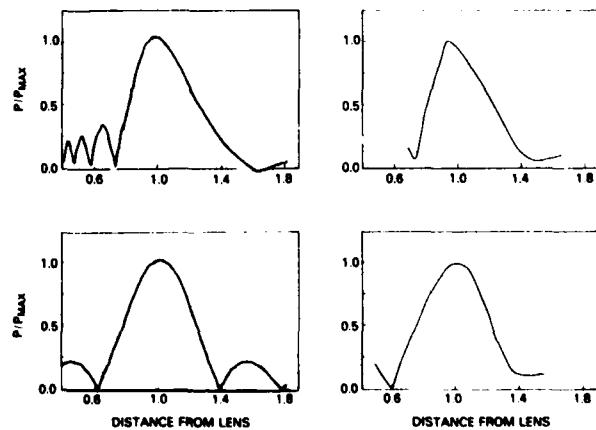


FIG. 5. Comparison of pressure on transducer axis through focal region, computed for lens on transducer face (upper left), measured with lens on face (upper right), computed with lens at one focal distance (lower left), and measured with lens at one focal distance (lower right).

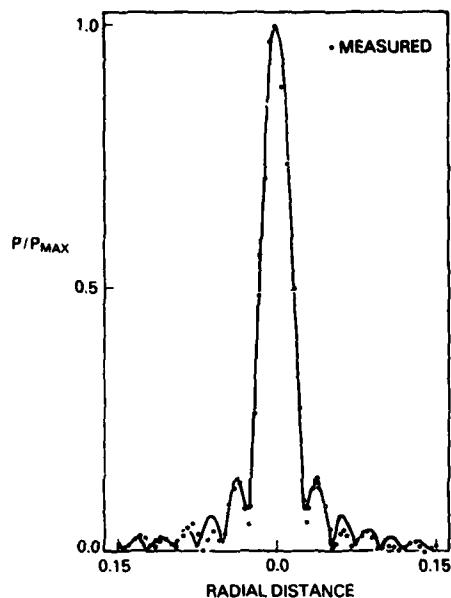


FIG. 6. Measured (○) and computer (-) pressure in the plane perpendicular to the transmitter axis at the point where the axial pressure is a maximum for the case where the lens is mounted on the transducer face.

angles encountered in the experiment.

Figure 2 illustrates the calculated fields for the two transducer-lens geometries. The top diagram illustrates the field obtained for the lens positioned at the transducer face; the same pattern can be expected for the situation of a transducer with a curved radiating surface. The lower diagram, for the lens positioned at one focal length, indicates a significant structural change occurs under these circumstances. In both cases, the abscissa measures the distance from the lens and the ordinate has been expanded to show the resultant spatial detail. Minor differences in the high degree of symmetry exhibited in the lower of the plots is a result of the computer graphic contour routine and not of the analytic development; in both instances the pressure peak in the diagrams is normalized to 0.0 dB and the contours chosen to map 3.0-dB intervals. The experimental and calculated values shown in the remaining figures expand only the central region of these detailed plots.

Measured and computed pressure profiles for the case where the lens is mounted at the transducer face are given in Fig. 3. The measured contour structure in this case is in good agreement with the predicted

values; the expanded scale of presentation allows verification of the location of the pressure peaks and nulls. In both diagrams, the contour nearest the peak is - 6.0 dB relative to the peak pressure; the remaining intervals are - 3.0 dB down (i.e., - 9.0 dB, - 12.0 dB, etc.). There is an experimental error of approximately 1.0 dB due to the nonlinear response of the measuring electronic equipment.

Figure 4 shows the measured and computed contours for the case where the acoustic lens is placed one focal distance from the transducer face. The measured pressure peak and nulls are again in good agreement with that of the calculation; the measured values verify the high degree of symmetry expected. Calculated and experimental pressure profiles along the transducer axis in the region of the pressure peak are shown in Fig. 5. The upper-left curve shows the calculated pressure for a lens mounted on the source face, the upper right shows the experimentally measured pressure. The lower curves repeat the process for the lens located at the focal distance. The calculated pressure curve in the plane perpendicular to the axis at the point of maximum axial pressure, a distance of approximately 0.96 in. from the lens, is plotted in Fig. 6, along with the experimentally measured values.

Experimental evidence indicates that the method of Cavanagh and Cook adequately predicts the pressure field of ultrasonic transducer-lens system. Calculations, performed point for point with the Gaussian-Laguerre algorithm, allow for quick computation. The results outlined in this work assume the lens large compared to the width of the sound beam. The analytic formulation has been extended to predict the field for finite size lenses. Additionally, the experimental evidence presented indicates the utility of the microsphere probe to spatially map with high resolution and precision the fields encountered in focused ultrasound.

<sup>1</sup>E. Cavanagh and B. D. Cook, "Nearfield of Ultrasonic Transducer-Lens Systems: Theory of the Gaussian-Laguerre Formulation," *J. Acoust. Soc. Am.* Suppl. 1 **66**, S46 (1979).

<sup>2</sup>E. Cavanagh and B. D. Cook, "Description of Ultrasonic Fields Using Gaussian-Laguerre Formulation. Numerical Example: Circular Piston," *J. Acoust. Soc. Am.* **68**, 1136-1140 (1980).

<sup>3</sup>P. L. Edwards and J. Jarzynski, "Experimental and Theoretical Study of the Scattering of Focused Ultrasound from Micro particles in Fluids," *J. Acoust. Soc. Am.* Suppl. 1 **65**, S128 (1979).

<sup>4</sup>P. L. Edwards and J. Jarzynski, "Use of a Microsphere Probe for Pressure Field Measurements in the Megahertz Frequency Range," *J. Acoust. Soc. Am.* **68**, 356-358 (1980).

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				<i>A</i>
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